5. HIGHLIGHTS OF LABORATORY ACTIVITIES IN 2007

This section highlights the Laboratory's accomplishments for 2007. The summaries of Branch activities in sections 5.1, 5.2, and 5.3, expand on the introductory paragraphs in section 2. They are written by the Branch Heads and give examples of the research carried out by Branch scientists and engineers. Additional activities are described in Section 5.4, Laboratory Research Highlights. These highlights are supplemented by news items related to the Laboratory in Appendix 1, by a complete listing of refereed articles that appeared in print in 2007 in Appendix 2, and by the first page of highlighted journal articles in Appendix 3. For more details on Branch science activities, the Branch Web sites can be accessed from the Laboratory for Atmospheres home page at http://atmospheres.gsfc.nasa.gov/.

5.1 Mesoscale Atmospheric Processes Branch, Code 613.1

The Mesoscale Atmospheric Processes Branch (MAPB) seeks to understand the contributions of mesoscale atmospheric processes to the global climate system. Research is conducted on the physical and dynamical properties and on the structure and evolution of meteorological phenomena, ranging from synoptic scale down to micro-scales, with a strong focus on the initiation, development, and effects of cloud systems. A major emphasis is placed on understanding energy exchange and conversion mechanisms, especially cloud microphysical development and latent heat release associated with atmospheric motions. The research is inherently focused on defining the atmospheric component of the global hydrologic cycle, especially precipitation, and its interaction with other components of the Earth system. Branch members participate in satellite missions and develop advanced remote sensing technology with strengths in the active remote sensing of aerosols, water vapor, winds, and convective and cirrus clouds. There are also world-class research activities in cloud system modeling, and in the analysis, application, and visualization of a variety of data.

The MAPB currently consists of 62 on-site personnel. Demographically, there are 12 civil service scientists (10 with Ph.D.s) and one civil servant clerical. The Branch maintains Cooperative Agreements with four institutions (UMBC/GEST, UMBC/JCET, GMU and UMCP/ESSIC), which collectively, comprise 23 scientists and programmers (21 Ph.D.s). Since 1990, the Branch has had a contractual relationship with SSAI of Lanham, MD, for scientific, engineering, computer and administrative support. The level of support is currently 21 onsite and 3 off-site personnel. Five other support persons are employed by RSIS, SGT, SAIC, Caelum, and Ecotronics. Three additional retired civil servants maintain Emeritus positions, as well as the GPM Project Scientist (Arthur Hou/GMAO) who is co-located in the Branch.

The Branch maintains a Web site at http://atmospheres.gsfc.nasa.gov/meso/, where current information on projects, field campaigns, publications, and personnel listings can be found. An important Branch asset is the GOES Project Science Web site (http://goes.gsfc.nasa.gov/) which displays real-time GOES imagery, and provides high-quality data to the scientific community. For example, in a non-hurricane month (May 2006), the site served 50 GBytes/day to 46 thousand distinct hosts at the average rate of 2 requests per second. During a hurricane, the Web server typically hits its limit of 10 requests per second to 150 simultaneous guests. The TRMM Web site (http://trmm.gsfc.nasa.gov/) provides near-real time precipitation estimations every 3 hours (with daily and weekly accumulations) as well as flood potential maps. A brief synopsis of virtually every major hurricane, typhoon, and flood event around the globe with attendant maps of accumulated precipitation can be found at http://trmm.gsfc.nasa.gov/publications_dir/multi_resource_tropical.html.

The Branch activities fall into three main subject areas, precipitation (and attendant climate-scale research), instrument development and data analysis (primarily lidars and radars), and numerical modeling. These are described in more detail below.

Precipitation

Branch scientists develop retrieval techniques to estimate precipitation using satellite observations from TRMM and other satellites, such as GOES and the AMSR-E sensor on EOS Aqua. The major accomplishments this year were in the areas of TRMM algorithm improvement, application of TRMM precipitation data sets to flood and landslide detection and monitoring, and achievement of continued operation of the TRMM satellite. In particular, there were significant publications on the TRMM Microwave Imager precipitation and latent heating profile products (Huffman et al. 2007; Olson et al. 2007; Shige et al. 2007; Tao et al. 2007). The overall accuracy of the TRMM algorithms continues to improve. The TRMM Ground Validation team supports this achievement through processing and analysis of data from rain gauge networks and ground-based radars. This team provides reliable, instantaneous area- and time-averaged rainfall data from several representative tropical and subtropical sites worldwide for comparison with TRMM satellite measurements. Ten years of high quality TRMM data are now available through the GES DISC. TRMM and other precipitation/latent heating data are used within the Branch for a wide spectrum of studies on precipitating cloud systems, the global water and energy cycles, and precipitation variability, particularly as it relates to ENSO (Curtis et al. 2007; Gu et al. 2007 - see Section 5.4.3). Increasingly, these activities integrate global or regional data sets with modeling. Research is conducted on the assimilation of TRMM observations into models to explore the potential benefits to weather forecasting, such as for hurricanes, and to improve understanding of precipitating cloud systems, particularly the diurnal cycle. An experimental global monitoring system for rainfall-triggered floods and landslides using the 3-hour TRMM precipitation product is currently under development.

Branch scientists also made significant contributions to the development of the Global Precipitation Measurement (GPM) mission in a wide range of areas including (1) definition of mission requirements and descoping options, (2) GPM participation in the highly successfully Canadian CloudSat/CALIPSO Validation Program (C3VP) field campaigns in the winter of 2006–07, (3) establishing joint ground validation plans with Finland, Canada, and France, and (4) working with the international community to develop a common reference standard for intercalibrations of GPM constellation radiometers, which is key to providing the next-generation global precipitation products for research and applications.

Instrument Development and Data Analysis

Development of lidar technology and application of lidar data for atmospheric measurements are also key areas of research. Systems have been developed to characterize the vertical structure and optical depth of clouds (CPL), atmospheric aerosols (MPLNET, CPL), water vapor (ALVICE, RASL), and winds (GLOW) at fine temporal and/or spatial resolution from ground-based or airborne platforms (CPL, RASL). In addition, the CPL and the Cloud Radar System (CRS), a millimeter-wavelength radar for profiling cloud systems, are instrument simulators and validation tools for CALIPSO and CloudSat, respectively. In June 2007, the CPL and CRS were flown on the ER-2 aircraft in support of the Department of Energy's Atmospheric Radiation Measurement (DoE-ARM) program's Cloud and Land Surface Interaction Campaign (CLASIC) field campaign. Immediately afterward, in July-August 2007, both CPL and CRS were flown on the ER-2 as a critical component of the TC4 mission (see Section 4.2.3). The airborne measurement synergy of the lidar (CPL) and cloud radar (CRS) is an important and unique capability of the Branch.

Development of three instruments funded from the IIP continued. TWiLiTE is an airborne direct detection Doppler lidar to measure wind profiles through the troposphere (0–17 km) using the laser signal backscattered from molecules. HIWRAP is a conical scanning Doppler radar to provide horizontal winds within precipitation and clouds, and ocean surface winds, in addition to more traditional 3-D radar reflectivity and hydrometeor characteristics. Both TWiLiTE and HIWRAP are on schedule for completion in 2008 with test flights in the fall on NASA's WB-57 high-altitude aircraft. Our airborne Raman lidar (RASL) was completed and flown in WAVES_2007 field campaign (see Section 4.2.4).

GLAS (the Geoscience Laser Altimeter System) was successfully launched aboard the Ice, Cloud and Land Elevation Satellite (ICESat) in early 2003. GLAS is an important part of NASA's Earth Science Enterprise (ESE), which includes a series of satellites to measure Earth's atmosphere, oceans, land, ice, and biosphere for a period of 10 to 15 years. During 2007, GLAS data analysis contributed to two submitted journal publications.

The NASA Micro Pulse Lidar Network (MPLNET) is a federated network of Micro Pulse Lidar (MPL) systems designed to measure aerosol and cloud vertical structure continuously, day and night, over long time periods required to contribute to climate change studies and provide ground validation for models and satellite sensors in the NASA Earth Observing System (EOS). At present, there are fourteen permanent sites worldwide, and four more to be completed soon (see Section 4.3.5). Numerous temporary sites have been deployed in support of various field campaigns since the start of MPLNET in 2000, and three more planned in 2008. Most sites are co-located with sites in the NASA Aerosol Robotic Network (AERONET) to provide both column and vertically resolved aerosol and cloud data. In addition to continuation of expansive network growth during 2007, all MPLNET data have been reprocessed into a new data release, version 2, which includes many new data products. Further information on the MPLNET project, and access to data, may be obtained online at http://mplnet.gsfc.nasa.gov.

The Raman lidar group is engaged in a broad range of research involving development and use of technologies for studying atmospheric quantities and processes. There is a substantial effort and collaboration with Howard University (HU). The Raman group taught a lidar techniques course within the HU Physics Department. The WAVES_2006 and WAVES_2007 Aura validation field campaigns have been focused at the HU Beltsville campus. The goals of these campaigns were to bring diverse instrumentation to one place for validation of satellite water vapor, ozone and clouds. WAVES_2007 included the first flights of the Raman group's Raman Airborne Spectroscopic Lidar (RASL) which flew in support of Aura and CALIPSO missions as well as for mesoscale studies and instrument comparisons. About twenty undergraduate and graduate students and many scientists from Howard University, GSFC, Penn State, Univ. of Virginia, Univ. of Colorado, NCAR, Maryland Department of Environment, USDA, NWS, and scientists from Italy, Bolivia, and Brazil have participated in the WAVES experiments. Details of the WAVES experiments, including links to activities, goals, pictures and more can be found at http://ecotronics.com/lidar-misc/WAVES.htm.

The Raman group also participated in the second Measurements of Humidity in the Atmosphere Validation Experiments (MOHAVE-II) experiment at JPL's Table Mountain Facility near Pasadena, CA. This deployment supported validation of Aura satellite measurements under the framework of the Network for the Detection of Atmospheric Composition Change (NDACC). MOHAVE-II was the first field deployment of the new ALVICE (Atmospheric Lidar for Validation, Interagency Collaboration and Education) lidar system and demonstrated its capability to profile water vapor throughout the troposphere and into the lower stratosphere. Ms. Felicita Russo received her Ph.D. degree from the University of Maryland, Baltimore County in May 2007, for work on new techniques for quantifying aerosol and cloud properties using lidar. Visiting scientists from Russia, Bolivia, and Brazil have also been recently supported.

Numerical Modeling

The Branch is active in the development, improvement and application of atmospheric modeling systems. Three major development efforts were achieved in the past year. The finite volume General Circulation Model (fvGCM—see also Section 4.5.4) and Goddard Cumulus Ensemble (GCE) model, a cloud-resolving model, were coupled in a multi-scale modeling approach. The use of the fvGCM allows global coverage, and the GCE model provides explicit simulation of cloud processes and their interactions with radiation and surface processes, in contrast with conventional parametric approaches. This modeling system has been applied and tested for two different climate regimes, El Niño (1998) and La Niña (1999). The new, coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems, diurnal variation of rainfall over land and ocean and intraseasonal oscillations, which are very difficult to forecast using conventional GCMs. A second major effort involved coupling various NASA Goddard physical packages (microphysics, radiation, and land surface models) into a next generation weather forecast model (known as the Weather Research and Forecast model or WRF). The new, coupled modeling system allows better forecasting (or simulation) of convective systems and tropical cyclones. Lastly, an improved GCE modeling system has been developed at Goddard over the last two decades. The GCE model has been recently improved to simulate the impact of atmospheric aerosol concentration on precipitation processes and the impact of land and ocean surface processes on convective systems in different geographic locations. The improved GCE model has also been coupled with the NASA TRMM microwave radiative transfer model and the precipitation radar model to simulate the satellite observed brightness temperature at various frequencies. This new, coupled model system allows us to investigate tropical cloud processes and improves the precipitation data retrieved from NASA satellites.

The same microphysical, long- and shortwave radiative transfer, explicit cloud-radiation, and cloud-surface interactive processes are applied in all three modeling systems. The results from these modeling systems were compared to NASA high-resolution satellite data (e.g., TRMM, CloudSat) in terms of surface rainfall and vertical cloud and precipitation structures. The model results were also compared to NASA and non-NASA field campaigns. The scientific output from the modeling activities was again exceptional with 15 new papers published in 2007.

Branch scientists conducted research in the areas of hurricane formation, structure, and precipitation processes with an emphasis on storms that occurred during special NASA field programs such as CAMEX-4 and the Tropical Cloud Systems and Processes (TCSP) experiment. Halverson et al. (2007) described the TCSP experiment and initial findings related to tropical cyclone formation and intensification. Wu (2007) found a close relationship between trends in hurricane intensity, Sahel rainfall, and Saharan Air Layer activity. Numerical forecast models, such as the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model (MM5) and the Weather Research and Forecasting (WRF) model, were applied to simulate observed storms at very high grid resolution. The results were compared to field program and satellite (e.g., TRMM) measurements. Analysis of results for Hurricane Erin (CAMEX-4, 2001) led to improved understanding of precipitation organization, storm structure, and their relationship to intensity change and environmental influences (Braun and Wu 2007). Cram et al. (2007), using an MM5 simulation of Hurricane Bonnie from CAMEX-3, examined transport and mixing processes between the eye and eyewall. They found mixing of low-level eye air possessing high thermodynamic energy into the eyewall, which serves to enhance the energy available for convective updrafts in the eyewall and increase the intensity of the storm. A study of the formation of Tropical Storm Gert (TCSP, 2005) is leading to improved knowledge of the processes that contribute to storm formation, particularly the role of deep convective towers. Deep convection tends to spin up cyclonic circulations at low levels while stratiform precipitation enhances mid-level cyclonic rotation. Using the WRF model, we found that, like in many convective systems, deep convection was most active in the earlier stages while stratiform precipitation peaked somewhat later as convective cells decayed. Consequently, the storm's cyclonic circulation developed first at lower levels and then intensified at mid-levels as stratiform precipitation formed. These results suggest more of a bottom-up development as opposed to the more canonical top-down hypotheses of development.

Numerical models and TRMM satellite data are also used to study the organization of precipitation in winter storms and the mechanisms responsible for that organization. We are studying the along-front variations in precipitation structure in a cold front and relating that structure to the synergistic interaction between lower- and upper-tropospheric cold fronts. We are also examining the detailed cloud-to-mesoscale structure of the same cold front and finding that the banding of precipitation within the cold-frontal rainband was related to the possible release of conditional symmetric instability.

5.2 Climate and Radiation Branch, Code 613.2

One of the most pressing issues we face is to understand the Earth's climate system and how it is affected by human activities now and in the future. This has been the driving force behind many of the activities in the Climate and Radiation Branch. We have made major scientific contributions in five key areas: hydrologic processes and climate, aerosol–climate interaction, clouds and radiation, model physics improvement, and technology development. Examples of these contributions may be found in the list of refereed articles in Appendix 2 and in the material on the Code 613.2 Branch Web site, http://climate.gsfc.nasa.gov.

Key satellite observational efforts from the Branch include MODIS algorithm development and data analysis. The new MODIS "collection 5" processing stream began in April 2006, starting with Aqua MODIS data. This processing stream includes substantial enhancements and updates to the operational cloud and aerosol products developed in the Branch. The availability of MODIS cloud and aerosol products is opening new pathways of research in climate modeling and data assimilation in the Laboratory. MODIS data analysis efforts included the role of 3D radiative effects on aerosol retrievals and a number of studies of 3D and non-plane parallel effects on cloud retrievals.

The MODIS-derived global annual direct aerosol radiative forcing over clear sky oceans was estimated to be -5.3 ± 0.6 Wm^{-2}. Attempts to quantify aerosol indirect effects on clouds included combining *in situ* cloud microphysics in California marine stratocumulus with TOA broadband CERES observations. An approach to quantifying the indirect effect on precipitation involved continuing analysis of six years of TRMM data which shows the existence of a weekly cycle. Over the continental U.S. in summer, rain intensity and area increase midweek when pollution is at its maximum while the opposite behavior occurs over nearby waters. This finding provides new insight into the influence of human activities on rainfall. The effect of aerosol loading on cloud cover using AERONET ground-based observations showed a positive correlation, in agreement with previous satellite studies.

Efforts to include explicit aerosol nucleation processes in climate models continued. Yogesh Sud led the McRAS (Microphysics of Clouds with Relaxed Arakawa-Schubert Scheme) effort. The new McRAS modules provide an end-to-end aerosol-cloud-radiation and precipitation scheme that explicitly handles CCN/IN activation and cloud formation, wet deposition, and cloud particle size distribution in fractional clouds for radiative calculations. The goal is to develop an aerosol–cloud–radiation interaction scheme that can credibly simulate direct and indirect aerosol effects.

In the applications area, high-resolution MODIS Aerosol Optical Depth (AOD) products (1, 2, and 5 km) are currently under evaluation as part of an on-going 3-dimensional air quality monitoring system project over the U.S. This 3-year effort (2006-2008) is funded by the NASA Application Program (Code YO), with a strong partnership with EPA (data system) and NOAA (air quality forecast). In addition, a 3-year Advanced Monitoring Initiative project (2006-2008) led at Goddard by Allen Chu (GEST/613.2), in support of GEOSS and funded by the EPA Pilot Program using high-resolution MODIS AOD products, is in full swing to study the air quality in the San Joaquin Valley, California. Both projects will incorporate CALIPSO, airborne, and ground-based lidar measurements to study the vertical distribution of aerosol. These two projects will provide insights into the relationship of satellite derived AOD and *in situ* PM2.5 mass concentration (for particles sizes less than 2.5 µm).

Branch members continued participation in NASA sponsored field campaigns, including NASA's Tropical Composition, Cloud, and Climate Coupling (TC4) campaign (summer 2007), and the DoE ARM Cloud and Land Surface Interaction Campaign (CLASIC, June 2007).

We continue to serve in key leadership positions on international programs, panels, and committees. Robert Cahalan chaired the Observations Working Group of the Climate Change Science Program (CCSP) Office, tasked to evaluate and coordinate multi-agency contributions to the U.S. Government climate observing system. Cahalan also chairs the 3-Dimensional Radiative Transfer Working Group of the International Radiation Commission and directs the International Intercomparison of 3-Dimensional Radiation Codes. Warren Wiscombe began his tenure as the DoE Atmospheric Radiation Measurement (ARM) Chief Scientist in October 2005; this appointment includes his half-time residence at Brookhaven National Laboratory. Wiscombe is also the American Geophysical Union (AGU) Atmospheric Sciences Section president.

Branch personnel continue to serve in key project positions. Robert Cahalan serves as project scientist of SOlar Radiation and Climate Experiment (SORCE) launched on January 25, 2003. SORCE is measuring both Total Solar Irradiance (TSI) and Spectral Solar Irradiance (SSI) with unprecedented accuracy and spectral coverage during a 5-year nominal mission lifetime. Deputy project scientists include Si-Chee Tsay (Terra), Steven Platnick (Aqua), and Christina Hsu (NPOESS Preparatory Project, starting in November 2006). Associate Branch member Michael D. King is the EOS Senior project scientist.

We continue to make strides in many areas of science leadership, education, and outreach. Thanks to the organizational efforts of the late Yoram Kaufman and the involvement of Lorraine Remer, Charles Ichoku (ESSIC/613.2) and other Branch members, the popular AeroCenter seminar series has continued into a seventh year. The biweekly seminars attract outside aerosol researchers from NOAA and the University of Maryland on a regular basis. The AeroCenter visitor program continues to reap benefits including joint paper submissions.

The Goddard Sun-Climate Center, like AeroCenter, is a cross-cutting activity within Goddard's Sciences and Exploration Directorate, and is co-hosted by the Climate and Radiation Branch and the Goddard Solar Physics Laboratory. The Center sponsors research on solar system climate, and investigates new opportunities for advancing the understanding of the Sun's forcing of Earth's climate. Visiting scientists from Germany and Japan have joined this effort, and the Center receives advice from an international panel of experts. The Center encourages new collaborations between scientists studying Earth, the Sun, and Earth's moon. See http://sunclimate.gsfc.nasa.gov.

The Branch benefits from our close association with the GSFC Earth Sciences Education and Outreach Program, most of whose members (including program manager David Herring, Code 610.3) reside in Branch space and utilize Branch resources. This group produces the Earth Observatory Web site that continues to provide the science community with direct communication gateways to the latest breaking news on NASA Earth Sciences, as well as the more recent NASA Earth Observations (NEO) data set visualization tool.

Finally, we continue with timely updates (often daily) to the Climate and Radiation Branch Web site (http://climate.gsfc.nasa.gov). Its "Image of the Week" and "Latest News" items highlight research by Branch members. A search page provides easy access to archived news, images, publications, and other climate information and data. The site supports calendar subscriptions and also has an extensive glossary of Earth science acronyms and a list of links to related sites.

5.3 Atmospheric Chemistry and Dynamics Branch, Code 613.3

The Atmospheric Chemistry and Dynamics Branch develops computer models and remote sensing instruments and techniques as aids in studies of aerosol, ozone, and other trace gases that affect chemistry, climate, and air quality on Earth. Using satellite, aircraft, balloon, and ground-based measurements, coupled with data analysis and modeling, Branch scientists have played a key role in improving our understanding of how human-made chemicals affect the stratospheric ozone layer.

Satellite Data Analysis and Records

Branch scientists have been active participants in satellite research projects. In the late 1960s, our scientists pioneered development of the Backscattered Ultraviolet (BUV) satellite remote sensing technique. Applying this technique to data taken from NASA and NOAA satellites, Branch scientists have produced a unique long-term record of the Earth's ozone shield. The data record now spans more than three decades, and provides scientists worldwide with valuable information about the complex influences of Sun, climate, and weather on ozone and ultraviolet radiation reaching the ground. We have updated our merged satellite total ozone data set through May of 2007. We have transferred the calibration from the original six satellite instruments to the NOAA 16 and NOAA 17 SBUV/2 instruments. We have further extended this intercalibration to include the OMI instrument on the Aura satellite. We also have a merged profile data set from the SBUV instruments. The data, and information about how they were constructed, can be found at http://code916.gsfc.nasa.gov/Data_services/merged. It is expected that these data will be useful for trend analyses, for ozone assessments, and for scientific studies in general. For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov) or Stacey Frith (smh@code916.gsfc.nasa.gov). Branch scientists expect to maintain this venerable record using data from a series of BUV-like instruments that are planned for use on U.S. and international satellites in the next two decades. Branch scientists were also instrumental in developing the UARS project which generates data used by researchers to produce a highly detailed view of the chemistry and dynamics of the stratosphere. Currently, Branch scientists are providing scientific leadership for the EOS Aura satellite, which was launched on July 15, 2004. Aura contains four advanced instruments to study the stratospheric ozone layer, chemistry and climate interactions, and global air quality. Branch scientists are also involved in the design of instruments, algorithms, and data systems for the new generation of ozone sensors on the operational weather satellites (NPP and NPOESS) and are developing state-of-the-art instruments to monitor air quality and tropospheric chemical species from spacecraft located at high vantage points (at distances ranging from 20,000–1,500,000 km from Earth). In addition, they operate a suite of advanced active and passive remote sensing instruments to study the chemical composition of the Earth's atmosphere from ground and aircraft. The Branch has recently developed an advanced instrument and algorithm capability for ground-based validation of OMI satellite aerosol, NO_2, SO_2, and O_3 data.

Modeling Activities

The measurement activities of the Branch are highly coupled with modeling and data analysis activities. The Branch maintains state-of-the-art 2-D and 3-D chemistry models that use meteorological data, produced by the GMAO and other research centers, to interpret global satellite and aircraft measurements of trace gases. Results of these studies are used to produce congressionally-mandated periodic international assessments of the state of the ozone layer, as well as to provide a strategic plan for guidance in developing the next generation of satellite and aircraft missions. A major new thrust of the Branch is to apply the unique synergy between Branch modeling and measurement groups, which proved very successful for the study of stratospheric chemistry, to study chemically and radiatively active tropospheric species, including aerosol, CO_2, O_3, CO, NO_x, and SO_2, which affect climate, air quality, and human health. The Branch's expertise in modeling atmospheric composition, including aerosols, has generated a new initiative to develop a coupled chemistry-climate model, using the GMAO Global Circulation Model.

The following provides more detailed descriptions of some of the current Branch activities:

3-D Stratospheric Chemistry Model Studies

The coupled chemistry climate modeling project brings together the atmospheric chemistry and transport modeling of the Atmospheric Chemistry and Dynamics Branch and the General Circulation Model (GCM) development of the GMAO. The initial goal is to understand the role of climate change in determining the future composition of the atmosphere. We have coupled our stratospheric chemistry and transport into the Goddard Earth Observing System (GEOS) general circulation model and will use this to study the past and future coupling of the stratospheric ozone layer to climate. Our emphasis is on the testing of model processes and model simulations using data from satellites and ground-based measurement platforms. We have run simulations of the past starting in 1950 and have extended them into the future to the year 2100. These simulations led to the discovery that ozone has increased in the middle stratosphere over the Antarctic during summers of the last two decades. The simulation was confirmed by examining data from the SBUV series of satellites. We are now setting up to run the scenarios being defined for the next ozone assessment using the same chemistry coupled into a new version of the general circulation model, GEOS-5. The GEOS-5 version has now been coupled to the combined stratosphere-troposphere chemistry model (COMBO) that has been developed under the Global Modeling Initiative (GMI). The GEOS-5/COMBO version of the CCM is being tested and will be used to attack scientific questions concerning the composition of both the troposphere and stratosphere and their interactions with the climate system.

Co-PIs are Richard Stolarski (Atmospheric Chemistry and Dynamics Branch) and Steven Pawson (Global Modeling and Assimilation Office). For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov), Steven Pawson (Steven.Pawson-1@nasa.gov), or Anne Douglass (Anne.R.Douglass@nasa.gov).

Global Modeling Initiative (GMI)

The goal of GMI is to develop and maintain a state-of-the-art modular 3-D CTM that can be used for assessing the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry, including the effects of aircraft. The GMI model also serves as a testbed for different process algorithms, emission inventories, parameterizations, and meteorological fields.

The components of the GMI model have been recoded for compliance with the Earth System Modeling Framework. The GMI model is being evaluated through comparison to satellite, aircraft, and ground-based measurements. The combined stratospheric-tropospheric model (COMBO), has been very successful in simulating the temporal and spatial distribution of ozone measured by Aura instruments, both in the stratosphere and upper troposphere. A “tape recorder” effect in CO measurements from MLS is reproduced by the model. This “tape recorder” is driven by the seasonality of biomass burning. The model has also compared well with tropospheric ozone columns derived from OMI and MLS measurements, and with CO from the AIRS instrument. Comparison to OMI tropospheric column of NO_2, as well as surface ozone measurements over Europe also show good agreement. Comparisons with satellite data, aircraft, and ground-based measurements are ongoing.

The GMI model has participated in the assessment carried out by the Hemispheric Transport of Atmospheric Pollutants (HTAP) international effort. Results from GMI simulations have been incorporated in the HTAP interim report, and will contribute to several scientific publications.

OMI Data Analysis

The OMI, built by Dutch/Finnish collaboration, was launched on NASA’s EOS Aura satellite in July 2004. The primary objective of OMI is to continue the long-term record, created by Branch scientists, of total ozone, tropospheric ozone, UVB, aerosols (primarily smoke and desert dust), and volcanic SO_2 using data from NASA’s TOMS instrument series. OMI is also designed to measure several other trace gases important for air quality studies, including NO_2, anthropogenic SO_2, HCHO, and BrO, with improved spatial and temporal resolution compared to data from previous instruments, the Global Ozone Monitoring Experiment (GOME) and the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY), on European satellites. Several Branch scientists are members of a NASA-funded U.S. science team, which is led by Pawan K. Bhartia. In 2005, Branch scientists developed and released several TOMS-like data products from OMI. Several new products, not previously available from TOMS, have also been produced and are currently being validated. These include cloud parameters such as cloud pressure that are appropriate for use within the OMI trace-gas algorithms. Several scientific papers describing this work were submitted to the special issue on Aura validation in the Journal of Geophysical Research. OMI products have been submitted to the data archive.

Global Aerosol Studies

Aerosols affect climate by scattering and absorbing solar radiation and by altering cloud properties and lifetimes. They also exert large influences on weather, air quality, atmospheric chemistry, hydrological cycles, and ecosystems. To understand the roles that aerosols play in the Earth system and to determine the processes that control the aerosol distributions, Branch scientists have developed the GOddard Chemistry Aerosol Radiation and Transport (GOCART) model which simulates major types of atmospheric aerosols and relevant trace gases originating from both anthropogenic and natural sources, such as fossil fuel combustion, biomass burning, desert, ocean, vegetation, and volcanoes. In addition to the original off-line version of the model which is driven by the GEOS-DAS assimilated meteorological fields from the Global Modeling and Assimilation Office (GMAO), the GOCART modules have been implemented into the on-line GEOS-GCM model as well as the Global Modeling Initiative (GMI) modeling framework in the past year by the Branch scientists to further enhance the modeling capability. The GOCART model and GEOS-5 were used to provide onsite forecasts of CO and aerosols during the Tropical Composition, Cloud, and Climate Coupling (TC4) campaign in the summer of 2007, and will be used in the spring and summer of 2008 to support the NASA Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) mission. Recently, collaborating with NOAA scientists, the GOCART model is being implemented into the regional model WRF-Chem and the NOAA Global Forecasting System (GFS) to expand its applications and serve the larger scientific community.

The modeling activities have been strongly connected to observations. For example, the model has been continuously used to analyze and interpret aerosol observations from satellite instruments of MODIS and MISR and from ground-based sun photometers in the AERONET network; the model output has been integrated into satellite observations to provide the best description of global aerosol distributions; the model vertical profiles of SO_2 and absorbing aerosols are being tested to facilitate OMI retrievals. The model has been a part of the international project AEROCOM (AEROsol Comparisons between Observations and Models) and has been used in the new international activities of Hemispheric Transport of Atmospheric Pollutants and the Atmospheric Chemistry and Climate initiatives. Results from GOCART simulations have been used to determine the contribution to polluted aerosol environments from both local sources and long-range transport.

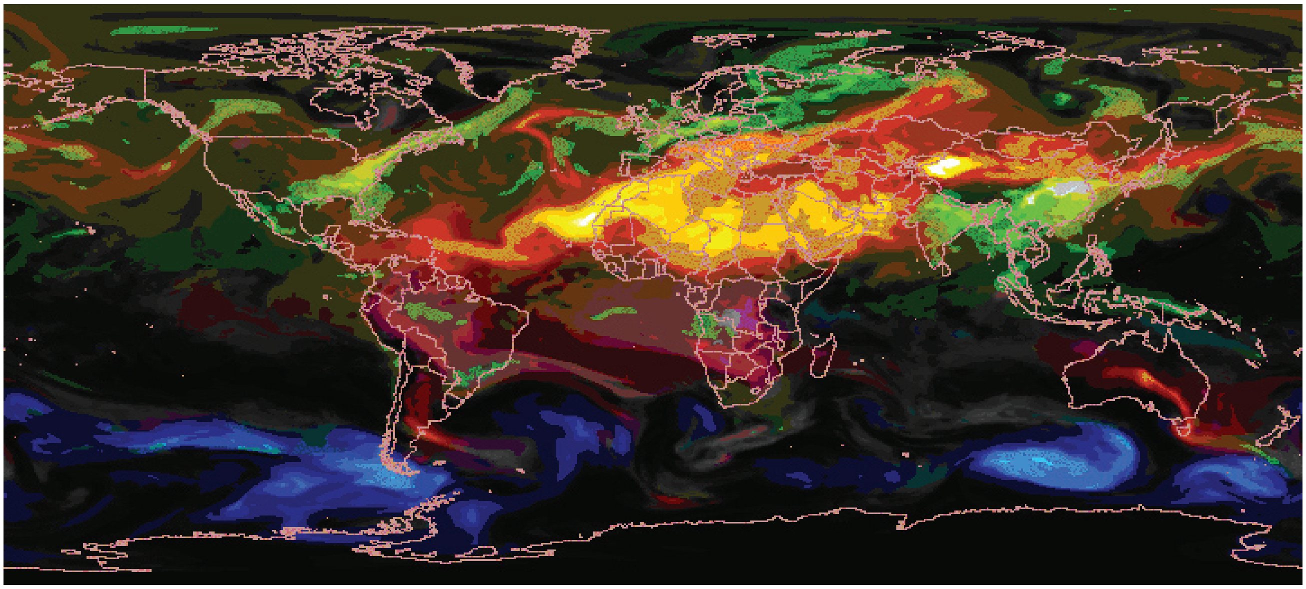

*Figure 5.1 Simulated global distribution of aerosol optical thickness for July 19 2007, from the GEOS-5 atmospheric general circulation model. The colors represent different aerosol species: blue = sea salt, cyan = carbonaceous, green = sulfate, and orange = dust. Brighter (darker) shading indicates greater (lesser) amounts of aerosol. These results illustrate the GEOS-5 model forecasts run at 0.5° × 0.666° horizontal resolution in support of the NASA TC4 campaign. Image is generated from the NASA TC4 WMS Viewer (*http://www.map.nasa.gov/cgi-bin/tc4-d5fcst-hwl.cgi*, Jeff de La Beaujardiere, Software Integration and Visualization Office, SIVO).*

Measurement and Modeling of Atmospheric Carbon Dioxide

Recent Laboratory progress in carbon cycle science has come in the areas of atmospheric transport modeling and instrument construction and testing. The atmospheric chemistry and transport model, used for calculating global CO_2 transport, has incorporated a land-biosphere emissions model and satellite data-constrained biomass burning emissions to produce CO_2 fields that are closely tied to actual meteorology and emission events. The modeling group is actively participating in an international model intercomparison exercise, TransComC, which is aimed at improving models' ability to utilize upcoming space-based CO_2 observations, such as the Orbiting Carbon Observatory. We continue collaborating with the GMAO in a new effort to develop a carbon cycle data assimilation system. We are also in a collaborative effort with the Solar System Exploration Division to develop an airborne CO_2 laser sounder under the IIP. The modeling effort will help to optimize the sounder measurement characteristics through observing system simulation experiments. A partner instrument, the ground-based laser CO_2 profiler, is also being developed in the Laboratory for Atmospheres. The laser profiler has recently achieved CO_2 detection in reflection from clouds and has made range-resolved measurements of aerosols at both the online and offline wavelengths. This is the final step in making range-resolved measurements of CO_2 within the planetary boundary layer. The real-time CO_2 observations will be compared with modeled distributions to improve our knowledge of the coupling between carbon cycle processes and climate change.

Solar Proton Events

Charles Jackman is using the Whole Atmosphere Community Climate Model (WACCM) to study the influence of solar proton events (SPEs) on the middle atmosphere (stratosphere and mesosphere). He is working on this endeavor with staff at the National Center for Atmospheric Research, where WACCM was developed. This work has focused on the very largest SPEs in the past 45 years. Comparisons between WACCM predictions and observations are generally reasonable for the SPE-caused production of polar NO_x ($NO + NO_2$) and the associated decrease in ozone during these very large solar events. He plans to continue this work and concentrate next on dynamically induced changes caused by the SPEs.

Instrumentation

Geostationary Spectrograph (GeoSpec) is a dual spectrograph operating in the UV/VIS and VIS/Near-Infrared (NIR) wavelength regions to measure trace gas concentrations of O_3, NO_2, and SO_2, coastal and ocean pollution events, tidal effects, and aerosol plumes. GeoSpec is intended to support future missions in the combined fields of atmospheres, oceans, and land. The Laboratory prototype, finished in late 2006, was used as a template for future mission studies in response to the NRC decadal survey. GeoSpec activities during the current year included continued testing and calibration such as an intercomparison campaign with the Washington State University MAXDOAS instrument. GeoSpec is a collaboration of our Laboratory, Pennsylvania State University, Washington State University, and Ball Aerospace and Technologies Corporation.

The Airborne Compact Atmospheric Mapper (ACAM) is an aircraft-based measurement program started in 2005. This system combines high resolution photographic imagery of both nadir and forward-looking cloud conditions with nadir UV and VIS spectrographic measurements in order to map trace gas concentrations of NO_2, O_3, and aerosols. ACAM activities included planning and redesign for a version to support deployment on a NASA UAV.

The 613.3 Stratospheric Ozone Lidar participated in the SAUNA II Campaign in Sodankylä, Finland during January and February, 2007 (Section 4.2.1). The purpose was to evaluate and quantify the problems that ozone column instruments have in making measurements at high solar zenith angles and high ozone levels. These instruments are important to the validation of satellite measurements at high latitudes. The lidar provided vertical profile, and atmospheric variability information for the interpretation of line of sight column ozone measurements.

5.4 Laboratory Research Highlights

5.4.1 Global Modeling

One of the strengths of 613.3 is that results from various models can be used to address the same issue. Douglass et al. (2007) uses output from the CGCM, the GMI CTM, the 2-D CTM, and a trajectory model to understand why *in situ* measurements from the ER-2 in the middle- and high- latitude lower stratosphere show that photolysis has broken apart significant fractions of the long-lived chlorofluorcarbons (CFCs) such as CF_2C_{12} and $CFCl_3$,even though the rate of destruction at the altitude of the measurement is insignificant. There is an observed compact relationship between the mean age of a parcel and the parcel fractional release, i.e., the amount of CFC that has been destroyed relative to the amount in the parcel when it crossed the tropical tropopause. This relationship is reproduced by simulations that produce realistic distributions for the mean age, but not by simulations that produce young age distributions as was common for both 2-D and 3-D models during the 1990s. The modern models that reproduce the observed relationships also produce longer lifetimes than the models that produce young ages, e.g., the lifetime for $CFCl_3$ that is consistent with the ER-2 observations for mean age and fractional release is about 56 years, significantly longer than the 45 years deduced from ground-based measurements and a simple model. This is important because the 45-year lifetime is used to produce the boundary conditions for assessment calculations (e.g., WMO 2007) or for projections of the recovery of the ozone hole (e.g., Newman et al., 2006).

5.4.2 Reversal of Trend of Biomass Burning in the Amazon

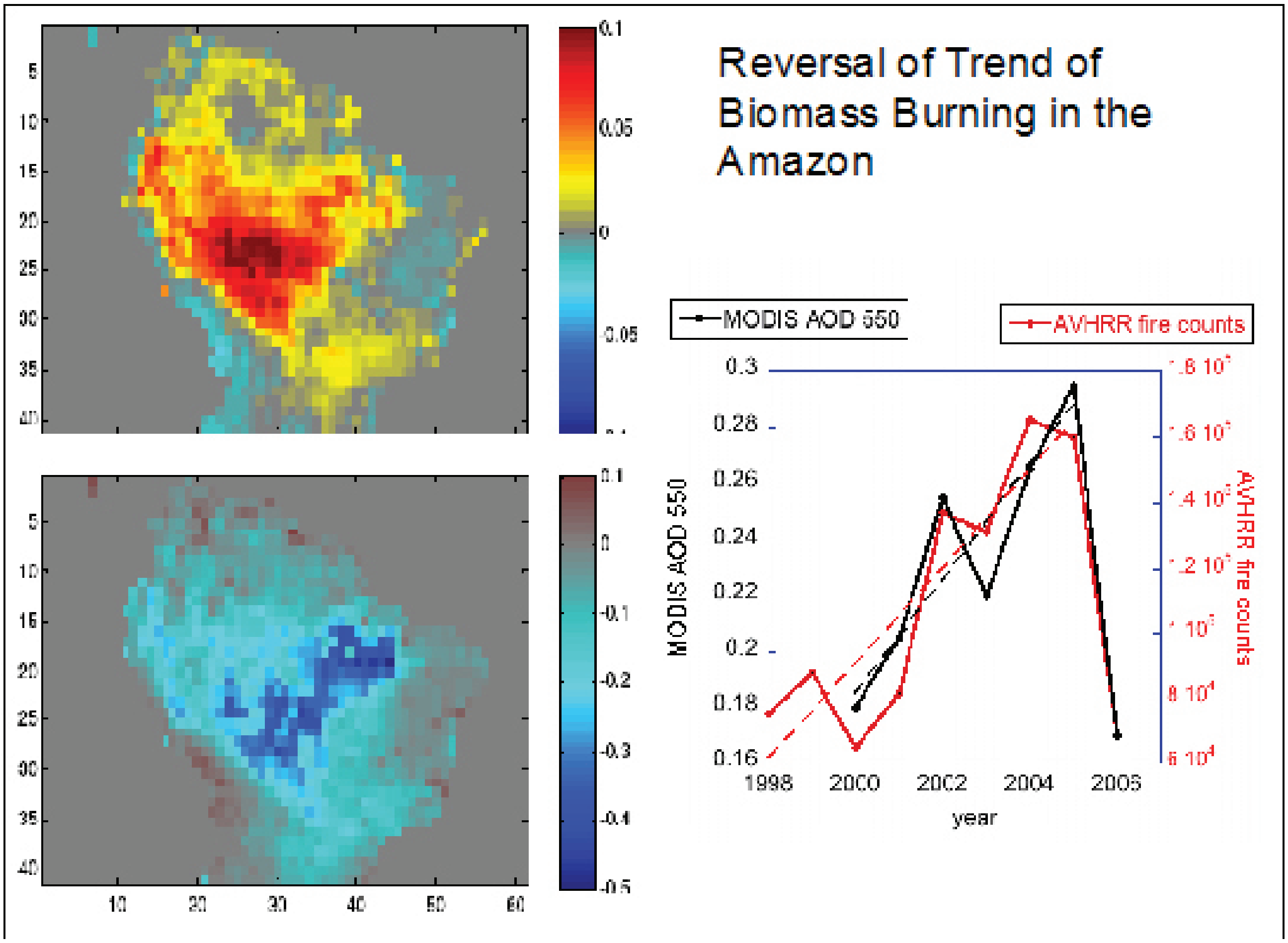

Figure 5.2 Reversal of trend of biomass burning in the Amazon.

Figure 5.2 illustrates the dramatic reversal of an increasing trend in biomass burning in just one year, due to a combination of human effort for change and meteorological factors.

The upper left panel provides the slopes of linear fits through six years of seasonal mean aerosol optical depth (AOD) as observed by the Terra–MODIS satellite sensor. The regressions were calculated independently for each 1-degree square. The biomass burning season is defined as August–November. The time series spans 2000–2005. We see that smoke increased over the entire Amazon Basin during this period. These trends are as high as 0.05 to 0.1 AOD per year, which represents an increase in AOD of 0.30 to 0.60 over the six-year period.

Then, suddenly, in 2006 there was much less smoke. The lower left panel shows the difference in the seasonal mean Terra MODIS AOD between 2005 and 2006. Blues indicate that 2006 had less smoke. The panel on the right shows the interannual variability in MODIS AOD averaged over the entire northern part of South America and also the total number of fire counts summed over the season as observed by AVHRR. We note the tight correlation between total number of fires and seasonal/regional mean AOD. We also note the tightly increasing trends upwards in both data sets until observations in 2006 reverse the trend.

Because the smoke was so alarming in 2005, a concerted effort was made by a coalition of governments, scientists, and civil authorities in 2006 to monitor burning and mitigate smoke production. Also in 2006, the rains came earlier. The result was dramatic. Smoke from biomass burning is a serious environmental hazard, but unlike earthquakes and severe weather, effective policy can mitigate the severity of the danger to human health, the well-being of the rain forest, and the whole climate system.

As a postscript, the analysis of Koren et al. (2007) ends with the 2006 fire season. In 2007, the Amazon did not benefit from early onset of rain, and perhaps fire mitigation practices were also relaxed, because the 2007 fire season in the Amazon was back at 2005 levels or higher, according to MODIS observations of AOD. For more information see Koren et al. (2007):

Koren, I., L.A. Remer, and K. Longo, 2007: Reversal of trend of biomass burning in the Amazon. *Geophys. Res. Lett.,* **34,** L20404, doi:10.1029/2007GL031530.

5.4.3 Tropical Rainfall Variability on Interannual-to-Interdecadal/Longer-Time Scales Derived from the GPCP Monthly Product

Analyzing global and regional variations in precipitation is an important part of understanding both climate variations in general and the possible implications of phenomena such as global warming. Possible changes or variations in precipitation are also important for their impacts on agriculture and water resources. The satellite-based, 27-year (1979–2005) Global Precipitation Climatology Project (GPCP) monthly precipitation data set provides the opportunity to examine part of this climate variation/change puzzle. This product is a community-based analysis of global precipitation under the auspices of the World Climate Research Program (WCRP) that uses information from various satellite measurements and ground-based rain-gauge data. We examined global and large regional precipitation variations and possible long-term changes, with a specific focus on the tropics (25°S-25°N), and found that, while the global linear change of precipitation in the data set is basically negligible during the time period, an increase in tropical rainfall is noted, with a weaker decrease over Northern Hemisphere middle latitudes.

The effects of ENSO and volcanic eruptions on the year-to-year variation of tropical precipitation are first examined. The ENSO events generally do not impact the tropical total rainfall, but induce significant anomalies with opposite signs over tropical land and ocean. Two major volcanic eruptions (El Chichón, March 1982; Pinatubo, June 1991) occurred during the time period. They induced up to a 5% reduction in tropical rainfall over both land and ocean. The derived relations are further applied to the GPCP data to isolate any long-term changes that are present. The increase in tropical total rainfall was especially evident over the oceans. Specifically, the data indicate an upward trend (+0.06 mm day^{-1}/decade) and a downward trend (-0.01 mm day^{-1}/decade) over tropical ocean and land, respectively (Figure 5.3a). This corresponds to a roughly 5.5% increase (ocean) and 1% decrease (land). After the ENSO and volcano effects are removed from the GPCP data (Figure 5.3b), these changes become more evident, and the (statistical) confidence levels used to estimate whether the change is real increase to higher levels. Furthermore, 2005 has the largest annual tropical total precipitation for the GPCP record. The five highest years are (in descending order) 2005, 2004, 1998, 2003, and 2002. For tropical oceans, the five highest years are 1998, 2004, 2005, 2002, and 2003. The major conclusion here is that the GPCP data set tends to support that tropical ocean precipitation appears to be increasing, possibly in reaction to "global warming". For further information, contact Robert F. Adler (Robert.F.Adler@nasa.gov), and Guojun Gu (Guojun.Gu-1@nasa.gov).

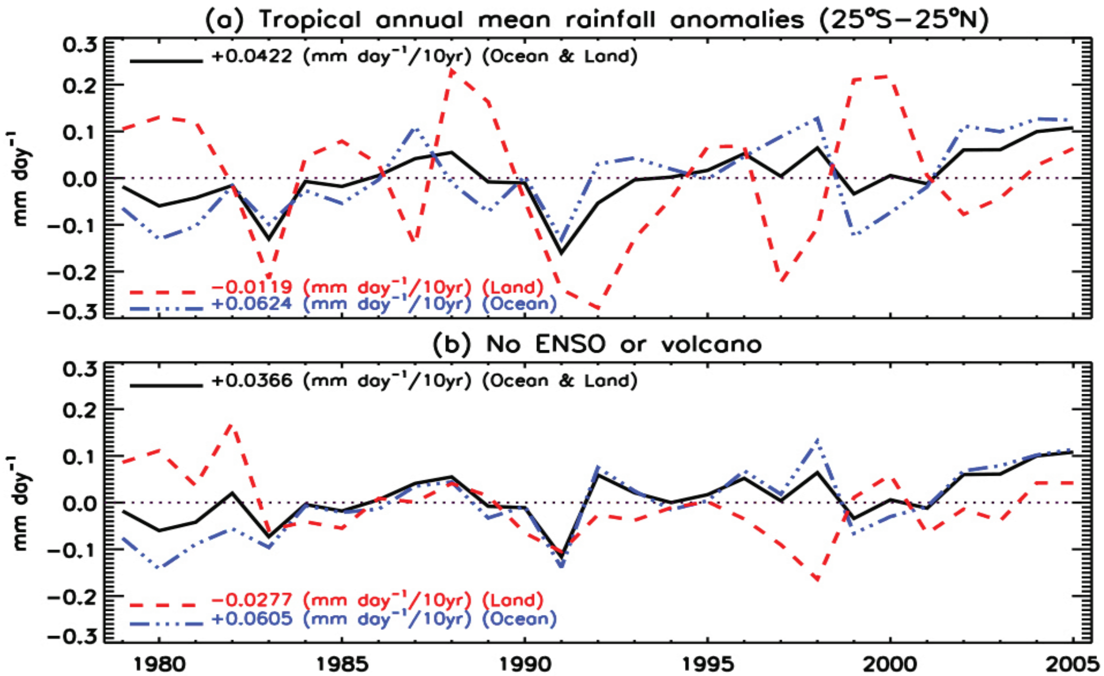

Figure 5.3 Tropical annual mean rainfall anomalies (a) with and (b) without the ENSO and volcano impact.

5.5 Instrument Development

The *Laboratory for Atmospheres Instrument Systems Report,* NASA/TP-2005-212783, described the status of instrument development in the Laboratory as of mid-2005. This section describes some of the developments since publication of that report.

High-Altitude Imaging Wind and Rain Airborne Profiler

A dual-wavelength (Ku and Ka band) High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) is under development for the NASA Instrument Incubator Program (IIP) for measuring tropospheric winds within precipitation regions and ocean surface winds in rain-free to light-rain regions. This instrument is being designed for operation on high-altitude manned aircraft and the Global Hawk UAV. Proposed lidar-based systems will provide measurements in cloud-free regions globally. Because many of the weather systems are in disturbed regions that contain precipitation and clouds, microwave-based techniques are more suitable in these regions. Airborne radars at NASA and elsewhere have shown the ability to measure winds in precipitation and clouds. These radars have not generally been suitable for deriving the full horizontal wind from above cloud systems (high-altitude or space) that would require conical scan. HIWRAP is a dual-beam, dual-wavelength conical scan radar that uses new technologies that utilize solid state rather than tube-based transmitters (Figure 5.4). Although primarily intended for atmospheric (precipitation) measurements, HIWRAP can serve as a QuikScat simulator with its Ku-band frequency and can provide measurements for GPM algorithm development since it has similar Ku- and Ka-band frequencies. Various subsystems of the radar are near completion and HIWRAP integration and testing will occur during spring 2008. The prototype sensor will be completed and tested on the high-altitude WB-57 aircraft in fall 2008 to demonstrate the system level performance of the instrument. For further information contact Gerry Heymsfield (Gerald.M.Heymsfield@nasa.gov).

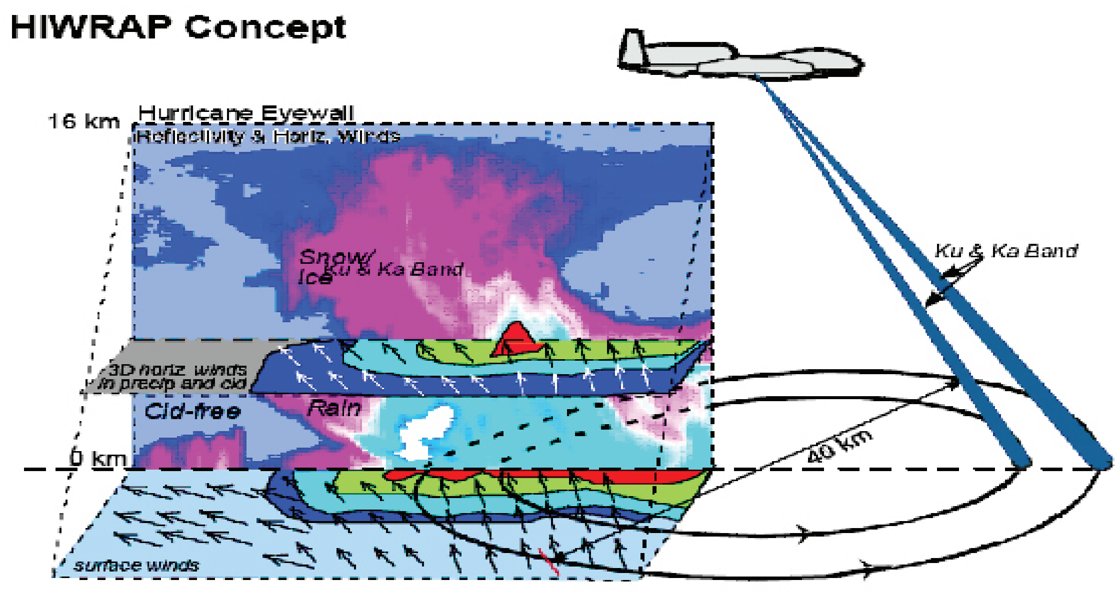

Figure 5.4 HIWRAP Concept

5.6 Awards and Special Recognition

5.6.1 Individual Awards or Recognition

Bob Adler (613) received the William Nordberg award at the Goddard Science Colloquium on November 16, 2007. The William Nordberg Memorial Award for Earth Science is presented annually to a Goddard employee "who best exhibits qualities of broad scientific perspective, enthusiastic programmatic and technical leadership on the national and international levels, wide recognition by peers, and substantial research accomplishments in understanding Earth science processes." This award recognizes Bob's outstanding long-term contributions to precipitation science, in particular his dedicated efforts as TRMM project scientist in ensuring the phenomenal success of that mission.

Thomas McGee (613.3) received the Alan Berman Research Publication Award from The Department of the Navy and NRL for technical merit and clarity. This award is for the publication entitled, "CHEM2D-OPP: A new Linearized Gas-Phase Ozone Photochemistry Parameterization for High Altitude NWP and Climate Model," on which he was a coauthor. The lead author was John McCormack of NRL and the publication appeared in Atmospheric Chemistry and Physics. The paper used our AROTAL data for comparison with the model results.

Scott Braun (613.1) was awarded the NASA Exceptional Scientific Achievement Medal on May 14, 2007, for his research on hurricane formation, structure, and intensification.

Winston Chao (613.2) was a NASA Honor Awards Recipient. He was awarded the Exceptional Achievement Medal.

Anne Douglass (613.3) and **William Lau** (613) were honored as AGU Fellows at the AGU Honors Ceremony held in conjunction with the AGU Joint Assembly, Acapulco, Mexico, May 22–25. Anne Douglass's citation reads "for significantly advancing the science of three-dimensional chemical modeling through the use of satellite and ground-based data," and William Lau's reads "for his outstanding contributions to the advancement of understanding of the monsoon climate system through original and masterful data analysis and modeling." The

AGU fellows are awarded annually to scientists who have acknowledged eminence in a field of space or Earth sciences, and are limited to 0.1% of the total AGU membership.

Paul A. Newman (613.3) has been selected by the 191 nations of the Montreal Protocol as one of the co-chairs of the Scientific Assessment Panel. The Montreal Protocol is the landmark agreement that regulates gases such as chlorofluorocarbons that deplete the ozone layer. The Panel assesses the status of and other scientific aspects of ozone layer depletion. The four Co-chairs are: Paul A. Newman (USA), A. R. Ravishankara (USA), John Pyle (UK), and Ayite-Lo Ajavon (Togo).

The Scientific Assessment Panel has been a pillar of the ozone protection regime since the very beginning of the implementation of the Montreal Protocol. Through provision of independent, technical and scientific assessments and information, this Panel has helped the world's nations reach informed decisions that have made the Montreal Protocol a world-recognized success. In accordance with the Montreal Protocol, the Panel carries out periodic assessments on the scientific issues of ozone depletion. The first report was published in 1989, and since then, major periodic assessments have been published in 1991, 1994, 1998, 2002, and 2006. The next one, for 2010, is expected to be published in 2011.

S.K. Satheesh (613.2/ORAU), an NPP Senior Fellow and Associate Professor with the Indian Institute of Science, currently visiting the Climate and Radiation Branch, has won the Scopus® Award for Earth Sciences. The Second Young Indian Scientist Awards were presented at an event held in New Delhi on December 7, 2007. Scopus® is the largest abstract and citation database of peer-reviewed literature and quality Web sources with smart tools to track, analyze, and visualize research.

5.6.2 Goddard Honor Awards

Alexander Marshak (613.2): GSFC Earth Science Achievement
N. Christina Hsu (613.2): Exceptional Achievement—Individual
Lorraine Remer (613.2): Outstanding Leadership

5.6.3 Group Achievement Awards

Matt McGill (613.1), **Bill Hart** (613.1/SSAI), **Dennis Hlavka** (613.1/SSAI), and **Steve Palm** (613.1/SSAI) are members of the CALIPSO Team that received a Group Achievement Award at the LaRC 2007 Honor Awards Ceremony on July 13. The citation reads, "For exceptional achievements in the successful development, launch, and operation of the CALIPSO satellite."

The first Environmental Research Letters Outstanding Article of the Year Award was presented to **Ilan Koren** (613.2/UMBC), **Yoram J. Kaufman** (613.2, Deceased), **Richard Washington, Martin C Todd, Yinon Rudich, J. Vanderlei Martins** (613.2/JCET) and Daniel Rosenfeld for the article "The Bodélé depression: a single spot in the Sahara that provides most of the mineral dust to the Amazon forest." In recognition of the outstanding contribution of this paper, each author has earned one-year free publication in ERL for themselves, as well as 6-months free publication for any paper submitted by any member of their institution. All published papers since 30 October 2007 will be considered for next year's award.

William Lau (613), **Gerry Heymsfield** (613.1), **Christina Hsu** (613.2), **Si-Chee Tsay** (613.2), and **Oreste Reale** (613/GEST) are members of the NASA African Monsoon Multidisciplinary Analysis (NAMMA) campaign that received an award for outstanding accomplishments in the successful NAMMA field campaign conducted in the Cape Verde Islands.